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(71) Applicant: **HITACHI, LTD.**
**6, Kanda Surugadai 4-chome**
**Chiyoda-ku, Tokyo 101(JP)**

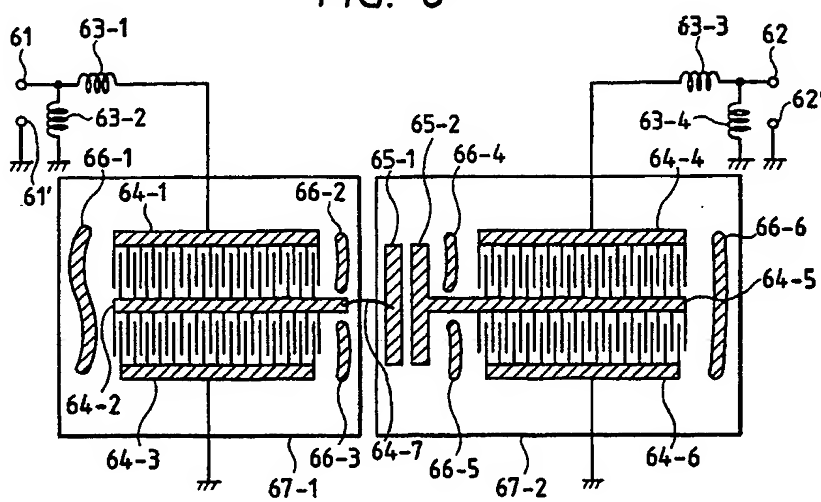
(72) Inventor: **Tabuchi, Toyoji**
**2648-2 Kawajiri, Shiroyama-cho**
**Tsukui-gun, Kanagawa-ken 220-01(JP)**
Inventor: **Hikita, Mitsutaka**
**30-7 Yokokawa-cho**
**Hachioji-shi, Tokyo 193(JP)**
Inventor: **Shibagaki, Nobuhiko**
**4-14-6 Nishikoigakubo**
**Kokubunji-shi, Tokyo 185(JP)**
Inventor: **Hirashima, Tetsuya**
**426-3 Tabiko**
**Katsuta-shi, Ibaraki-ken 312(JP)**

(74) Representative: **Patentanwälte Beetz sen. - Beetz jun. Timpe - Siegfried - Schmitt-Fumian- Mayr**
**Steinsdorfstrasse 10**
**W-8000 München 22(DE)**

(54) **Surface acoustic wave device and communication apparatus.**

(57) A surface acoustic wave device is disclosed for use in a communication apparatus. It has a multiple of surface acoustic wave elements (64-1 to 64-6) having different filter characteristics formed on individual piezoelectric substrates (67-1, 67-2), the different filter characteristics being synthesized to form a combined filter having a desired filter characteristic.

FIG. 6




EP 0 422 637 A2

# SURFACE ACOUSTIC WAVE DEVICE AND COMMUNICATION APPARATUS

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

The present invention relates to a surface acoustic wave device and a communication apparatus, and more particularly concerns a surface acoustic wave device and a communication apparatus especially preferable for use in mobile radio communication and cellular radio communication such as mobile telephones and pagers.

### 2. Description of the Related Art

A conventional surface acoustic wave filter is formed on a piezoelectric substrate in combination of a transducer for converting an electrical signal to surface acoustic wave and a transducer for converting the surface acoustic wave to electrical signal. The surface acoustic wave filter of the type is described, for example, in an article in the IEEE Trans., Microwave Theory and Techniques, MTT-33, (1985) pp510-518. In a prior mobile telephone system for simultaneous transmission and reception with use of a single antenna, the antenna is connected to input or output of a transmitter surface acoustic wave filter and receiver surface acoustic wave filter through an appropriate feeder line. It is described, for example, in an article in the IEEE Trans., Microwave Theory and Techniques, MTT-36, (1988) pp1047-1056. The transmitter surface acoustic wave filter and receiver surface acoustic wave filter is implemented in a single module, and an antenna duplexer is connected to an antenna terminal of a two-way transceiver of the mobile telephone system.

A prior filter constructed with coupled SAW resonators described, for example, in the Japanese Patent Laid-Open 63132515 consists of combination of a multiple of one-port surface acoustic wave resonators formed on a single piezoelectric substrate. The filter characteristic synthesis or cutoff frequency response is determined in terms of electrode structure of the resonator.

## SUMMARY OF THE INVENTION

However, the prior surface acoustic wave filter or duplexer of combined surface acoustic wave filters heretofore used, has the disadvantage that it is not available in parts of the European mobile telephone system and the like that the transmitter and receiver frequency bands are very wide and the transmitter and receiver band intervals are very narrow.

Also, the prior art has the disadvantage of problem that a low loss in a pass band is inconsistent with a high insertion loss in a stop band. In the mobile telephone system and similar communication systems, the band intervals are made narrow because of effective use of frequencies. The filters, therefore, are needed to have a sharp cutoff frequency response. In a circuit construction using a multiple of surface acoustic wave resonator, it is needed to use a narrow band one-port resonator that particularly affects a rejection characteristic in the vicinity of the pass band. In order to accomplish the narrow band resonant characteristic, it is advantageous to use a substrate having low electro-mechanical coupling coefficient. It, however, is defective in increased loss because of low conversion efficiency. If the substrate having low electro-mechanical coupling coefficient to achieve the sharp cutoff frequency response, the loss is increased because a resonator for insertion loss synthesis at frequencies away from the pass band is formed on the same substrate.

In order to solve the foregoing problems of the prior arts and to achieve other purposes, the present invention has following features: In accordance with one aspect of the present invention, a surface acoustic wave device comprising a first surface acoustic wave element having a first filter characteristic and a second surface acoustic wave element having a second filter characteristic, the first and second surface acoustic wave elements being provided on a first and second piezoelectric substrates, respectively, and the first and second filter characteristics being made to synthesize to form a combined filter having a desired filter characteristic,is provided.

The first and second surface acoustic wave elements may include a device called the transducer comprising at least two electrodes having a multiple of finger electrodes allocated to be interpolated into each other, for example, on the piezoelectric substrate. There may be conductive thin wires, slits, and/or grooves formed on the surface of the substrate of piezoelectric material or non-piezoelectric material on which piezoelectric film is coated. An input electric signal is converted to surface acoustic wave once that can propagate on the piezoelectric substrate. The excited surface acoustic wave is inversely converted to electric signal. This feature allows the surface acoustic wave device to have a filter characteristic referred to in the present invention. The first and second

surface acoustic wave devices referred to in the present invention, therefore, may be any surface acoustic wave devices as long as they have the filter characteristic mentioned above even if they are named resonators, for example, "one-port resonator".

In accordance with a limited aspect of the present invention, the surface acoustic wave device as set forth, wherein the first piezoelectric substrate has a first electro-mechanical coupling coefficient, and the second piezoelectric substrate has a second electro-mechanical coupling coefficient, is provided. A combined filter is formed of surface acoustic wave elements of different electro-mechanical coefficients of the piezoelectric substrates. The combined filter can have a sharp cutoff frequency response with low loss. In other words, the synthesized filter formed of a multiple of surface acoustic wave elements can have, for example, a pass band and stop band in terms of the resonance characteristics of the elements (resonators). As the surface acoustic wave element formed on the piezoelectric substrate having small electro-mechanical coefficient has a narrow band, it can be used to synthesize rejection portions in the vicinity of the pass band to accomplish sharp cutoff response. As the surface acoustic wave element formed on the piezoelectric substrate having large electro-mechanical coefficient, it has resonant characteristics of high exciting efficiency of surface acoustic wave and wide band. It can be used as a resonator for rejection portions away from the pass band where no sharp frequency responses are not needed. This allows low loss and high rejection characteristics to be accomplished. The combined filter of the surface acoustic wave elements formed on the multiple of piezoelectric substrates having different electro-mechanical coefficients, is available as a filter consistent for both sharp low loss and high rejection. This effect can be obtained in the way that the combine filter is formed of the surface acoustic wave elements on the piezoelectric substrates having different electro-mechanical coefficients. It can be easily understood that such an effect can be obtained in a way that the multiple of piezoelectric substrates having different coefficients are further provided on a common substrate.

In accordance with still another aspect of the present invention, it is provided the surface acoustic wave device as set forth, wherein the surface acoustic wave device also comprises a first package and a second package, the first surface acoustic wave element being provided in the first package, and the second surface acoustic wave element being provided in the second package. The multiple of surface acoustic wave elements forming the combined filter sealed in the different packages, cannot be achieved unless the first and second surface acoustic wave elements mentioned above are provided on the different substrates according to the present invention. This feature of the present invention provides significant effects in making small and light communication apparatuses such as mobile telephone and portable telephone.

In accordance with another limited aspect of the present invention, it is provided the surface acoustic wave device as set forth, wherein the surface acoustic wave device further comprises a signal filter having a third filter characteristic. With the signal filter further formed of surface acoustic wave element on the same piezoelectric substrate as the first surface acoustic wave element or second surface acoustic wave element, it can be made further small and light. The surface acoustic wave device used in a communication apparatus such as portable telephone has a single antenna. According to the present invention, therefore, the surface acoustic wave device can be achieved so that a signal received by the antenna and a signal transmitted by the antenna can be filtrated through the combined filter mentioned above and the signal filter mentioned above.

There are provided a duplexer comprising a transmitter and receiver filters and a mixer circuit comprising a receiver second filter and local filter. The receiver and receiver second filters are required to have a particularly high performance frequency response. Usual surface acoustic wave filters are not available as having no sharp frequency response. In the present invention, the transmitter filter in the duplexer can compensate the defect, and the filter in the mixer formed in the same chip or package as the local filter can compensate the defect. This means that the required frequency response can be attained from the antenna terminal to receiver terminal and from the receiver terminal to the mixer.

One advantage of the present invention can accomplish a surface acoustic wave device and communication apparatus that provide a sharp filter cutoff frequency response and low loss and high rejection characteristics.

Another advantage of the present invention can accomplish a surface acoustic wave device and communication apparatus available for miniaturization and light weight.

Further another advantage of the present invention can accomplish a surface acoustic wave device and communication apparatus available for a system having a wide transmitter and receiver band widths and a narrow interval between the transmitter and receiver bands.

Still further advantages of the present invention will become apparent to those of ordinary skill in the art upon reading and understanding the following detailed description of preferred embodiments.

## BRIEF DESCRIPTION OF THE DRAWINGS

The invention may take from in various parts and arrangements of parts. The drawings are only for purposes of illustrating the preferred embodiments and are not to be construed as limiting the invention.

Fig. 1A is a circuit diagram illustrating a communication apparatus of one embodiment according to the present invention.

Fig. 1B is a perspective view illustrating a surface acoustic wave device of the embodiment according to the present invention.

Fig. 2A is a circuit diagram illustrating an embodiment in which the present invention is applied to a duplexer.

Fig. 2B is a circuit diagram illustrating an embodiment in which the present invention is applied to a mixer.

Fig. 3A is a graph illustrating a duplexer reception filter frequency response.

Fig. 3B is a graph illustrating difference between a receiver filter frequency response and a frequency response required for a receiver system.

Fig. 3C is a graph illustrating a receiver system frequency response accomplished according to the present invention.

Fig. 3D is a graph illustrating a duplexer transmission filter frequency response.

Fig. 4A is a circuit diagram illustrating an embodiment of a surface acoustic wave device according to the present invention.

Figs. 4B and 4C are diagrams illustrating an embodiment of a surface acoustic wave device according to the present invention.

Fig. 5A is a circuit diagram illustrating another embodiment of the surface acoustic wave device according to the present invention.

Fig. 5B is a perspective view illustrating further another embodiment of the surface acoustic wave device according to the present invention.

Fig. 6 is a diagram illustrating an embodiment of the surface acoustic wave device according to the present invention.

Fig. 7A, 7B, and 7C are a structure, equivalent circuit, and impedance characteristic illustrating a one-port resonator, respectively.

Fig. 8 is an equivalent circuit illustrating an embodiment of the surface acoustic wave device according to the present invention.

Fig. 9 is a diagram illustrating a conventional surface acoustic wave device.

Fig. 10A and 10B are pass band frequency responses of a surface acoustic wave device according to the present invention and a conventional surface acoustic wave device, respectively.

Fig. 11A, 11b, and 11C are views illustrating fabricating processes of further more another embodiment of a surface acoustic wave device according to the present invention.

Fig. 12A, 12B, 13A, and 13B are graphs illustrating frequency responses of a one-port resonator in series arm and shunt arm connections.

Fig. 14 a block diagram illustrating an embodiment of a communication apparatus according to the present invention.

## DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

For the purpose of illustration only, the present invention will now be illustrated by the following embodiments. Of course, the present invention shall not be limited to the following embodiments. The same numbers in the drawings represents the same arrangements.

In the accompanying drawings, Fig. 1A and 1B is a schematic representation of an embodiment of the present invention. In the figures, the number 1 represents an antenna, 2 is a transmission line, 3 is a receiver first stage filter, 4 is a transmitter filter, 5 is a band rejection filter, 6 is a receiver terminal, 7 is a transmitter terminal, 8 is a package base, 9-1, 9-2, 9-3, and 9-4 are package bonding pads, 10-1, 10-2, 10-3, and 10-4 are lead wires, 11 is a surface acoustic wave (SAW) filter, 13 is a package electric terminal, and 14 is a package cap. Fig. 1A shows a construction of a duplexer distributor used in a simultaneous transmission-reception radio apparatus such as a mobile telephone.

In general, the duplexer consists of a transmitter filter and a receiver filter, allowing transmission and reception with a single antenna. The conventional duplexer, as shown in Fig. 2A, is constructed in the manner that the transmitter filter 4 and receiver filter 3 are connected in parallel to the antenna terminal through the appropriate transmission lines 2.

A mixer section shown in Fig. 2B which uses a circuit construction well similar to the duplexer is used. In the figure, the number 15 represents an intermediate frequency terminal, 16 is a mixer, 17 are transmission lines, 18 is a receiver second stage filter, 19 is a local filter, 20 is a receiver terminal, and 21 is a local filter terminal. In the mixer section, similarly, the receiver second stage filter 18 and the local filter 19 are connected in parallel to an input of the mixer 16 through the appropriate transmission lines 17.

With the recent progress of the surface acoustic wave filter, this can be made to replace the usual filters 3, 4, 18, and 19 shown in Fig. 2A and 2B which are combination of dielectric resonators. In fact, the mobile telephones in the North Ameri-

can countries partly use the surface acoustic filter. However, parts of the mobile telephone systems in European countries, unlike the North American system, uses very wide transmission and reception frequency bands and very narrow transmission and reception band intervals. This means that the filters have to have a sharp cutoff frequency response. Such a characteristic cannot be achieved by the usual surface acoustic wave filters.

The present invention allows the surface acoustic wave to be used even in the systems for which the usual surface acoustic wave cannot be used. This will be described below with reference to Fig. 1A. As an example, the frequency response of the receiver filter 3, as shown in Fig. 3A, is not sufficient at all for the currently most wide band requirements of the mobile telephone system in Europe, particularly in the insertion loss at low frequencies. In the present invention, the duplexer has the transmitter filter and receiver filter built in so that such a desired frequency response as shown in Fig. 3C can be obtained as evaluated between the antenna terminal and receiver terminal 6.

In general, the transmitter filter 4 has a filter characteristic of band rejection type that the transmission band is a pass band and the reception band is an attenuation band as shown in Fig. 3D. The receiver filter shown in Fig. 3A is insufficient in a wedge-like band rejection characteristic shown in Fig. 3B as compared with the one required between the antenna terminal and receiver terminal Rx shown in Fig. 3C. The wedgelike band rejection characteristic is similar to the characteristic of the transmitter filter 4 shown in Fig. 3D. The filter pattern for achieving that characteristic is not similar to the receiver filter pattern at all. It is very like the transmitter filter pattern.

In view of the problem mentioned above, Fig. 1A shows a circuit that is formed to attain in the same chip or package as the transmitter filter 4 the characteristic insufficient between the antenna terminal and receiver terminal Rx shown in Fig. 3B. The surface acoustic wave filter can be usually formed in a thin film process as with semiconductor IC. It is desirable in view of the yield increase that filters of similar pattern should be formed in the same process. It is necessary for the surface acoustic wave filter to add external inductors to cancel out capacitances between electrodes of a surface acoustic wave exciting transducer as shown in Fig. 4A. (In the actual circuit, micro-strip lines are used to form the external inductors as shown in Figs. 4B and 4C.) In the figures, numbers 23 and 25 indicate matching inductors, 24 is the surface acoustic wave filter, 26 and 27 are transmission lines, 28 is a ground, 29 is a circuit substrate, 30 is a through hole, 31 is a ground, 32 and 33 are patterns formed on the circuit substrate, 34 is a matching network, and 35 is a surface acoustic wave filter. The receiver filter 3, for example, has a similar external circuit inserted in its input and output terminals. It is impossible to form the characteristic shown in Fig. 3B in the receiver filter in that view. It has to be formed in another chip in addition to the external circuit. In order to make the whole circuit small, it is preferable that the chip (pattern) should be same as the one for the transmitter filter 4 or it should be implemented in the same package.

The actual circuit of the present invention is shown in Fig. 1A. The figure is chiefly related to the duplexer that allow the transmitter system Tx and receiver system Rx to use a single antenna. The transmitter filter 4 and the filter 5 having the characteristic shown in Fig. 3B are formed in the same chip or package. The signal wave incoming to the antenna terminal passes through the appropriate transmission line 2 and is input to the receiver filter 3 through the filter 5. This can achieve the frequency response (Fig. 3C) needed between the antenna terminal and terminal Rx. The size of the whole circuit, as seen from the figure, is same as that of the duplexer having the usual surface acoustic wave filter shown in Fig. 2a.

The chip configuration and embodiment are shown in Fig. 1B. In the figure, a four pin flat package has the filters 4 and 5 (Fig. 1A) formed on a single chip 11. Pins 9-1 and 9-2 of the package correspond to the antenna terminal and receiver filter terminal of the filter 5. Pins 9-3 and 9-4 of the package correspond to the input and output terminals of the transmitter filter 4.

As stated in the foregoing description, the present invention allows the surface acoustic wave filter to be available in the North American system, but also in parts of the European mobile telephone systems that are very wide in the transmission and reception bands and very narrow in the intervals of the transmission and reception bands. Use of the circuit of the present invention will not change the volume of the package and the size of the whole circuit at all.

In Fig. 1A is taken the duplexer as the embodiment that the transmitter system Tx and receiver system Rx can use a single antenna in common. Similar construction can be made for a mixer as shown in Fig. 2B. The mixer is to convert, for example, a receiver signal to intermediate frequency in a way that the receiver signal and a local oscillator frequency signal are applied to a nonlinear device such as a transistor, FET, or diode to take out difference frequency of the two signals.

Fig. 2B shows that the receiver second filter 18 and local filter 19 are connected through the appropriate transmission lines 17 to the mixer 16. This

allows the signal received at the terminal Rx and the local oscillator frequency signal at the terminal Lo to be input to the mixer 16. The frequency response of the receiver second filter 18, however, is not sufficient for the parts of the European mobile telephone systems as with the duplexer in Fig. 1A.

The local filter 19 has a filter characteristic of band rejection type as with the duplexer transmitter filter 4 in Fig. 1A. This filter characteristic is used to form the wedge-like band rejection characteristic which is not sufficient by the receiver second filter 18. The wedge-like band rejection characteristic can be formed in the same chip or package as the local filter 19. The actual circuit of the foregoing is shown in Fig. 5A. In the figure, a number 15 represents an intermediate frequency terminal, 16 is a mixer, 17 are transmission lines, 18 is a receiver second filter, 19 is a local filter, 20 is a receiver terminal, 21 is a local filter terminal, and 22 is a band rejection filter. The signal wave incoming to the antenna terminal Rx passes through the receiver second filter 18. It then is input to the filter 22 and is passed through the appropriate transmission line 17 to the mixer 16. This can achieve the necessary frequency response between the terminal Rx and mixer 16.

The present invention cannot always have the filters 4 and 5 formed in the same chip as in Fig. 1B. The filters formed in different chips, as shown in Fig. 5B, can be implemented in the same package to provide the equivalent function.

This and following paragraphs describe a few embodiments using different piezoelectric substrates in detail. Fig. 6 shows a structure of an embodiment of the filter constructed with coupled SAW resonators according to the present invention. The filter is formed of four one-port resonators made of electrodes 64-1, 64-2, 64-3, 64-4, 64-5, and 64-6 and one gap capacitor made of electrode patterns 65-1 and 65-2 on two piezoelectric substrates that can propagate the surface acoustic wave. The electrodes 64-2 and 65-1 are electrically connected together with a bonding wire 64-7. In the figure, a number 61 indicates an input terminal, 61′ is an input grounding terminal, 62 is an output terminal, 62′ is an output grounding terminal, 63-1, 63-2, 63-3, and 63-4 are matching inductors with external circuits, and 66-1, 66-2, 66-3, 66-4, 66-5, and 66-6 are sound absorption material to absorbs the surface acoustic wave leaking out of the resonators. It should be noted that the electro-mechanical coupling coefficient of the piezoelectric substrate 67-1 is lower than the piezoelectric substrate 67-2. Each resonator consists of an interdigital transducer made up of multi-pair finger electrodes that are interpolated into each other. The interdigital transducer can be one-port resonator in which vibration energy can be confined with internal reflection by the finger electrodes themselves even without reflectors on the both sides.

In Fig. 7A is shown a one-port surface acoustic wave resonator which is a multi-pair finger transducer consisting of common electrodes 79 and 70. In the figure, a number 77 denotes a piezoelectric substrate, 78 is an input terminal, and 78′ is an output terminal. An electrically equivalent circuit of the resonator is given in Fig. 7B. In this figure, a number 71 denotes an equivalent inductor, 72 is an equivalent capacitor, and 73 is an electrostatic capacitor. Fig. 7C shows an impedance characteristic of the resonator in Fig. 7A where fr is a resonance frequency, and fa is anti-resonance frequency.

The filter in Fig. 6 can be represented by an equivalent circuit in Fig. 8, including a series arm resonator consisting of an equivalent inductor 71-1, an equivalent capacitor 72-1, and an electrostatic capacitor 73-1 and a shunt arm resonator consisting of an equivalent inductor 71-2, an equivalent capacitor 72-2, and an electrostatic capacitor 73-2 which are cascade-connected as looked into the input, and including a series arm resonator consisting of an equivalent inductor 71-4 an equivalent capacitor 72-4, and an electrostatic capacitor 73-4 and a shunt arm resonator consisting of an equivalent inductor 71-3, an equivalent capacitor 72-3, and an electrostatic capacitor 73-3 which are cascade-connected as looked into the output, the input and output cascade-connected resonators being connected through a cap capacitor 84.

Fig. 9 shows a schematic diagram of a usual combined resonator filter. The filter has all resonators formed on a single piezoelectric substrate 67. It can be represented by the equivalent circuit in Fig. 8 as with the one in Fig. 6. The equivalent components of the resonators in Fig. 6 and 9, however, are different in terms of material constants of the piezoelectric substrates.

Fig. 10A and 10B show results of simulated calculations of the frequency responses of the filters in Fig. 6 and 9, respectively. The frequency allocation used here as an example is the 800 MHz band which is used in parts of the European mobile telephone systems. The band requirement is defined in terms of a band width BW and an interval ΔfB between a stop band and a pass band. Fig. 10A shows the frequency response of the filter (Fig. 6) of the present invention. Fig. 10B shows the frequency response of the filter of usual type (Fig. 9). It can be seen from the figures that the filter of the present invention has a very sharp cutoff frequency response and a little insertion loss as well. The usual filter cannot obtain the sharp cutoff frequency response enough to meet the band requirement. Its insertion loss is low around the center portion of the pass band, but does not

meet the requirement outside it.

In comparison of the frequency responses in Fig. 10A and 10B, lower frequency poles (resonant frequencies) $f_1$ and $f_2$ and higher frequency poles (anti-resonant frequencies) $f_3$ and $f_4$ in Fig. 10A correspond to lower frequency poles $f_1'$ and $f_2'$ and higher frequency poles $f_3'$ and $f_4'$ in Fig. 10B. The poles, however, are greatly different in that $f_2 > f_2'$ and $f_3 < f_3'$. In general, the sharpness of the cutoff frequency response is determined by degrees of the poles ($f_2$ and $f_3$ in Fig. 10A and $f_2'$ and $f_3'$ in Fig. 10B) nearest to the pass band that can be made to approach to the pass band without affecting the characteristic of the pass band. In Fig. 10B, as compared with in Fig. 10A, the insertion loss at lower frequencies of the pass band is increased by effect of $f_2'$ irrespective of the fact that $f_2 > f_2'$; also, the insertion loss at higher frequencies is increased by effect of $f_3'$ irrespective of the fact that $f_3 < f_3'$.

This paragraph describes differences of the characteristics in Fig. 10A and 10B in view of differences of the structures of the filters shown in Fig. 6 and 9. The lower frequency pole $f_2$ closest to the pass band in Fig. 10A is formed by the input shunt arm resonator in Fig. 6 (which correspond the equivalent circuit consisting of 71-2, 72-2, and 73-2 in Fig. 8). That is, the resonant frequency of the shunt arm resonator coincides with $f_2$. The higher frequency pole $f_3$ closest to the pass band in Fig. 10A is formed by the input series arm resonator in Fig. 6 (which correspond the equivalent circuit consisting of 71-1, 72-1, and 73-1 in Fig. 8). That is, the anti-resonant frequency of the series arm resonator coincides with $f_3$. Similarly, the other lower and higher frequency poles $f_1$ and $f_4$ coincide with the resonance frequency of the output shunt arm resonator and the anti-resonance frequency of the output series arm resonator in Fig. 6, respectively. These relationships identically apply to the filters shown in Fig. 10B and 9. The poles $f_2'$ and $f_3'$ near to the pass band coincide with the resonant frequency of the input shunt arm resonator and the anti-resonance frequency of the input series arm resonator in Fig. 9, respectively. The other poles $f_1'$ and $f_4'$ coincide with the resonant frequency of the output shunt arm resonator and the anti-resonant frequency of the output series arm resonator, respectively.

As can be seen from the foregoing description, the difference of the filter shown in Fig. 6 from the one in Fig. 9 is the difference of the multiple of piezoelectric substrates from the single piezoelectric substrate. In other words, the filter of the present invention shown in Fig. 6 features that a desired filter characteristic can be synthesized using the multiple of piezoelectric substrates. The frequency responses of the one-port resonators formed on the piezoelectric substrate 67-1 having low electro-mechanical coupling coefficient and on the piezoelectric substrate 67-2 having high electro-mechanical coupling coefficient that are connected to the shunt arms are shown in Fig. 12A and 12B. Those of the ones that are connected to the series arms are shown in Fig. 13A and 13B. Frequency distance between the resonant frequency fr and anti-resonant frequency fa of the resonator is a function of the electro-mechanical coupling coefficient. The frequency distance is short as the coupling coefficient is low. The resonator forming the attenuation poles $f_2$ and $f_3$ near the pass band in Fig. 10A has to be sharp, therefore, it is to be formed on the piezoelectric substrate having low coupling coefficient to make the band narrow. The resonator formed on the piezoelectric substrate having high coupling coefficient, on the other hand, is advantageous in view of the insertion loss as its resonance characteristic is wide. It also has a high conversion efficient from electric signal to acoustic signal or acoustic signal to electric signal with low loss as its coupling coefficient is high. In order to form the attenuation poles $f_1$ and $f_4$ away from the pass band in Fig. 10A which need no particular sharpness, the piezoelectric substrate having high coupling coefficient. As explained in the foregoing, it is possible to accomplish sharp cutoff frequency response. Low loss, and high rejection characteristic in the way that the filter should be made up of resonators formed on a multiple of piezoelectric substrates.

The numbers of series arm and shunt arm resonator stages are different depending on the requirements such as filter band width and rejection level. With increase of the number of resonators, the filter design can be optimized by increasing the kinds of substrates.

The construction of the present invention using a multiple of piezoelectric substrates provides high effect if the filter has a proper pass band and stop band and is narrow between the both bands. In particular, it is effective if the relative band width which is ratio of the band width to center frequency is not less than 1 % and if the ratio of the band interval to center frequency is not more than 5 %.

The electro-mechanical coupling coefficient $k_2$ of the piezoelectric substrate is determined in terms of the kind of piezoelectric material, its cut angle, and propagation direction. Examples of the coupling coefficients of the known piezoelectric materials include around 19 % in the 41°-rotated Y-cut X-propagation of $LiNbO_3$, around 11.5 % in the 64° X-rotated Y-cut X-propagation of the same, around 7.6 % in the 36°-rotated Y-cut X-propagation of $LiTaO_3$, and around 0.16 % in the ST-cut quartz X-propagation. If the filter band has to be wide, it tends to increase the number of resonators

needed for band synthesis. For the purpose, it is desirable to combine the substrates having high coupling coefficient. For relatively narrow band width, it is possible to use the substrates having low coupling coefficient. It is common in any combination that the substrate having low coupling coefficient is to be used for characteristic synthesis in the vicinity of the pass band. A preferable range of coupling coefficient of the piezoelectric substrate forming a resonator of narrow band in the vicinity of the pass band is 0.1 to 10 %. A preferable range of coupling coefficient of the piezoelectric substrate forming a resonator of wide band away from the pass band is not less than 3 %. In particular, for wide band characteristic the relative band width of which exceeds 2 % as in the filters for use in mobile telephone, preferable coupling coefficient is not less than 10 %.

Further, the present invention can be made more effective by forming on the piezoelectric substrate having lower coupling coefficient the resonator the band width of which is made narrow by the electrode structure proposed above by the inventors or by forming the resonator of wide band on the piezoelectric substrate having higher coupling coefficient.

The temperature coefficient of a piezoelectric material is specific to it. In general, the temperature coefficient is low as the electro-mechanical coupling coefficient is low. As example, the temperature coefficient of the LiNbO3 substrate mentioned previously is around 50 to 60 ppm/°C, that of the $LiTaO_3$ substrate is around 30 ppm/°C, and that of the ST-cut quartz substrate is 0 ppm/°C at room temperature. A range of the interval between the pass band and stop band in which the present invention is more effective, as mentioned previously, is lower than 5 % as the ratio to the center frequency. If the working temperature range of the filter be a room temperature Tr±50°C, the range of 5 % mentioned above corresponds to a frequency change of the filter with the temperature coefficient of 500 ppm/°C. This means that preferable temperature coefficient of the piezoelectric substrate forming the resonator in the vicinity of the pass band is lower than 50 ppm/°C. For the substrate forming the resonator away from the pass band, it is lower than 80 ppm/°C though its temperature coefficient may be relatively high.

As an example, the multiple of substrates can be fabricated in the way that as shown in Fig. 6, filter elements are made to chips from specific substrates and are implemented in can package, ceramic package, or resin mold package. Fig. 11A, 11b, and 11C show other examples in which two or more kinds of materials having different electromechanical coupling coefficients are formed on a single substrate. Fig. 11A shows the example that one or more piezoelectric substrates 115 of different coupling coefficients are laminated on a part of a single piezoelectric substrate 114. Fig. 11b shows the example that two or more piezoelectric materials of different coupling coefficients are laminated on the substrate 116 such as silicon, sapphire, or glass. The lamination processes in Fig. 11A and 11b include a process for bonding the chips and a process that piezoelectric thin films are formed by way of radio frequency spattering. The both processes an provide the same effect for the filter characteristic. Fig. 11C shows the example that a single piezoelectric substrate is ionized or ion diffused on parts thereof to form area of different coupling coefficient. After this, the surface acoustic wave resonator(s) are formed on the substrate and made up as shown in Fig. 6 to accomplish the present invention.

The air gap provided between the two substrates, as shown in Fig. 6, can reduce direct coupling between their input and output by electric line of force passing through the piezoelectric substrates, thus improving the rejection frequency response in the stop band. This effect is same for the identical and different kinds of substrates.

The filter made up of the multiple of surface acoustic wave resonators according to the present invention provides superior power handling characteristics to transversal filters. It is particularly advantageous in use where the output power required is more than 0.1 watt as it can withstand an output power of watt order in a minute chip as small as 3 by 3 mm$^2$.

The surface acoustic wave filter of the present invention can be used in a mobile telephone so that this can be assembled to small size and light weight. It also can be used as radio frequency filter for commercial and sanitation apparatus so that these can be made small and light.

Fig. 14 is a block diagram for a portable telephone set constructed with use of a duplexer 142 of the present invention shown in Fig. 1A. The voice of a person is converted to electric signal through a microphone, which is input to a transmitter part 145. The transmitter part 145 can modulate and amplify the input signal. The output signal is transmitted outside from an antenna 141 through the duplexer 142. A signal received by the antenna 141 is filtrated through the duplexer, and is input to a receiver part 143 including a mixer circuit shown in Fig. 2B and 5A. The receiver part can amplify and demodulate the signal to reproduce the voice.

A logic part 147 can set a channel in a cell according to a signal from a cellular radio base station.

As described in the foregoing embodiments, the present invention features that one filter' function can be achieved with use of a multiple of

different filters in the way that parts of the frequency response needed for one filter is formed in the same chip or package as the other filter. This surface acoustic wave device which has been usually available only in the North American system, can be also made in the systems like the parts of the European mobile telephone system that the transmitter and receiver band widths are very wide and the intervals between the transmitter and receiver bands are very narrow.

## Claims

1. A surface acoustic wave device comprising:
a first surface acoustic wave element (64-1,64-2) having a first filter characteristic; and
a second surface acoustic wave element (64-1,64-2) having a second filter characteristic;
wherein the first and second surface acoustic wave elements are provided on a first and second piezoelectric substrate (67-1,67-2), respectively, and the first and second filter characteristic are made to synthesize to form a combined filter having a desired filter characteristic.

2. A surface acoustic wave device as set forth in Claim 1, wherein the first piezoelectric substrate has a first electro-mechanical coupling coefficient, and the second piezoelectric substrate has a second electro-mechanical coupling coefficient.

3. A surface acoustic wave device as set forth in Claim 1, wherein the surface acoustic wave device also comprises a first package and a second package, the first surface acoustic wave element being provided in the first package, and the second surface acoustic wave element being provided in the second package.

4. A surface acoustic wave device as set forth in Claim 1, wherein the surface acoustic wave device further comprises a signal filter (3,18) having a third filter characteristic.

5. A surface acoustic wave device as set forth in Claim 4, wherein the surface acoustic wave device further comprises a receiver and transmitter antenna, (1;141) a signal received by the antenna and a signal transmitted by the antenna being filtrated through the combined filter and the signal filter, respectively.

6. A surface acoustic wave device as set forth in Claim 4, wherein the signal filter is formed of surface acoustic wave filter.

7. A communication apparatus comprising:
an antenna (1;141) for receiving or transmitting a signal;
a first surface acoustic wave element (5) having a first filter characteristic electrically connected to the antenna (1;141); and
a second surface acoustic wave element (3) having a second filter characteristic electrically connected to the first surface acoustic wave element (5);
wherein the first and second surface acoustic wave elements are provided on a first and a second piezoelectric substrate (67-1,67-2), respectively, and the first and second filter characteristics are made to synthesize to form a combined filter having a desired filter characteristic.

8. A communication apparatus as set forth in Claim 7, wherein the first piezoelectric substrate (67-1) has a first electro-mechanical coupling coefficient, and the second piezoelectric substrate (67-2) has a second electro-mechanical coupling coefficient.

9. A communication apparatus as set forth in Claim 7, wherein the communication apparatus also comprises a first package and a second package, the first surface acoustic wave element being provided in the first package, and the second surface acoustic wave element being provided in the second package.

10. A communication apparatus as set forth in Claim 7, wherein the communication apparatus further comprises a signal filter having a third filter characteristic.

11. A communication apparatus as set forth in Claim 7, wherein the communication apparatus further comprises a receiver and transmitter antenna (1;141), a signal received by the antenna and a signal transmitted by the antenna being filtrated through the combined filter and the signal filter (3), respectively.

12. A communication apparatus as set forth in Claim 7, wherein the signal filter is formed of surface acoustic wave filter.

FIG. 1A

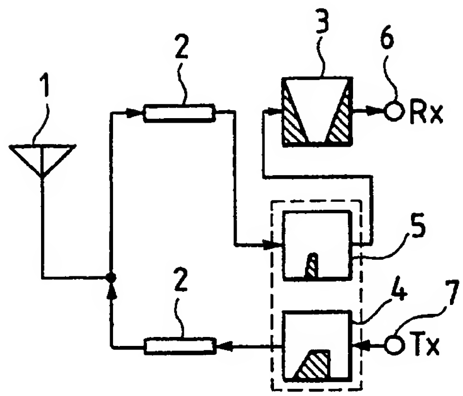



FIG. 1B

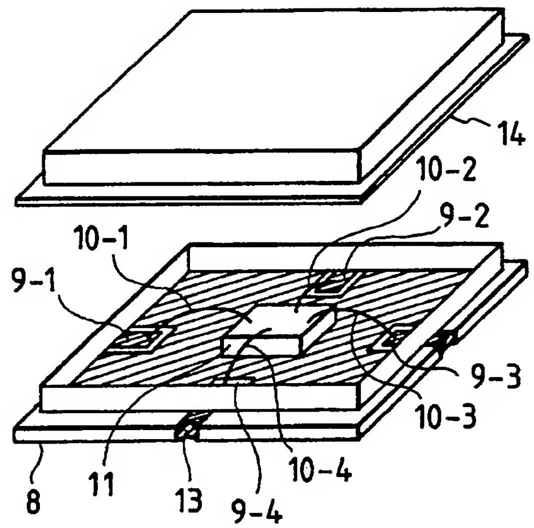



FIG. 2A

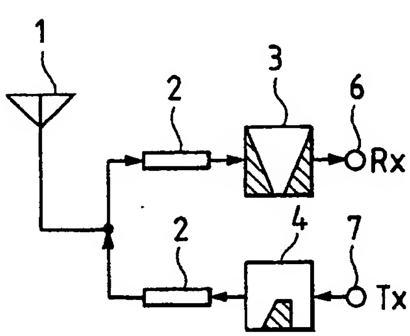



FIG. 2B

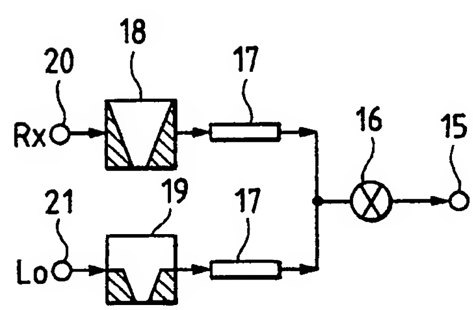


FIG. 3A

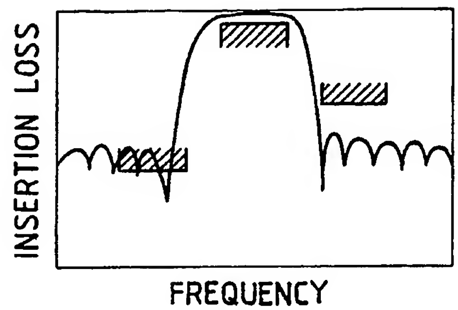



FIG. 3B

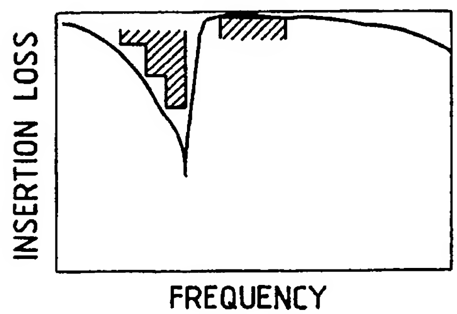



FIG. 3C

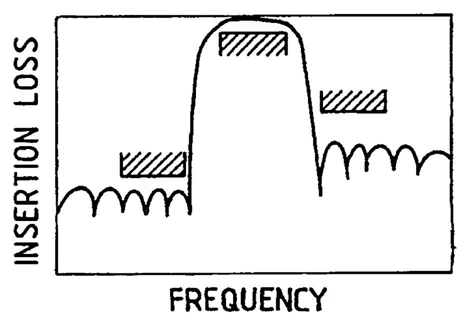



FIG. 3D

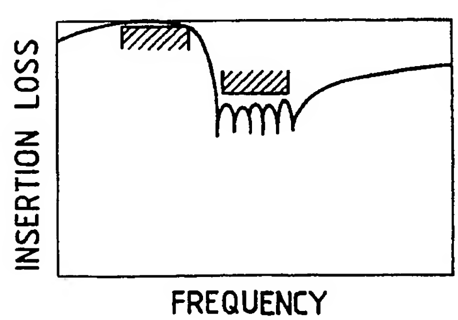


FIG. 4A

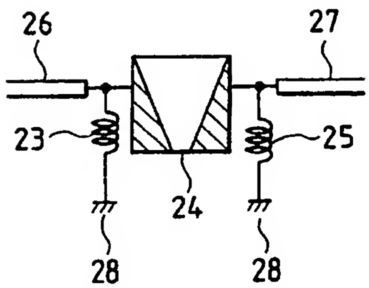



FIG. 4B

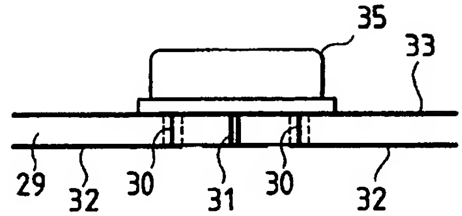



FIG. 4C

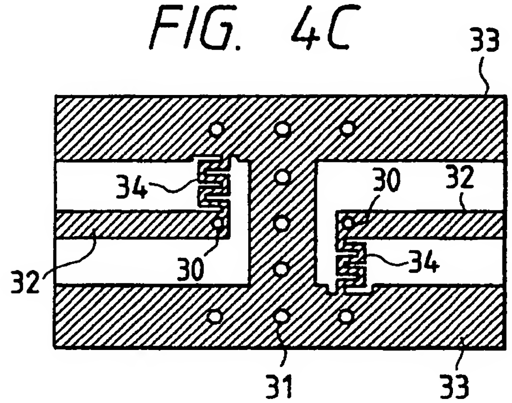



FIG. 5A

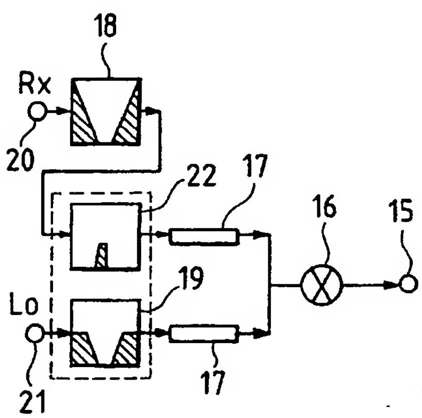



FIG. 5B

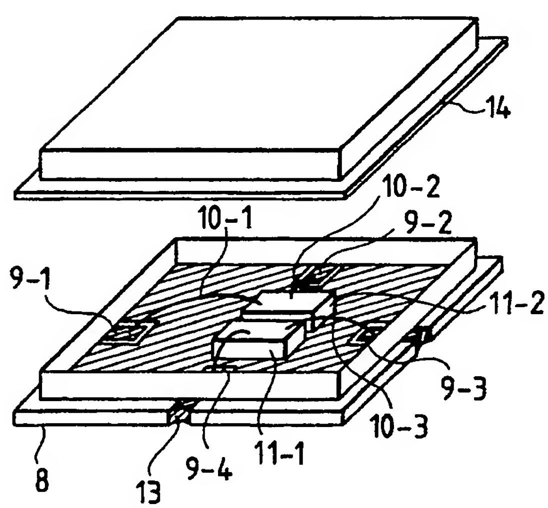


FIG. 6

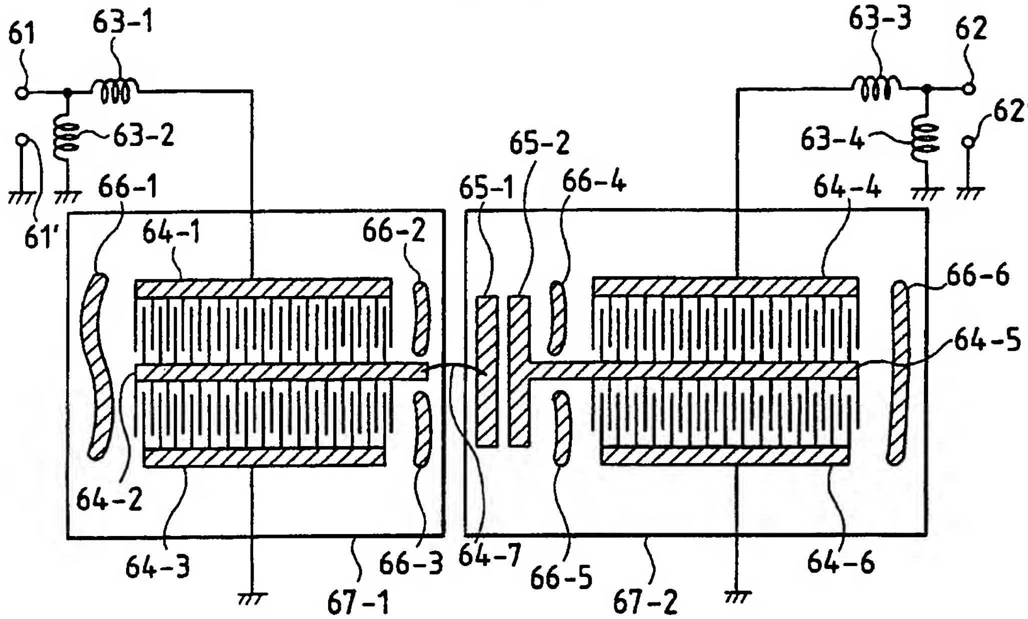



FIG. 11A

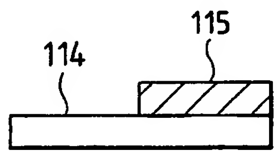



FIG. 11B

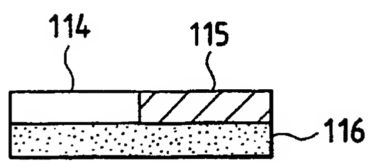



FIG. 11C

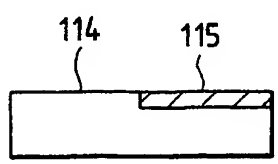


FIG. 7A

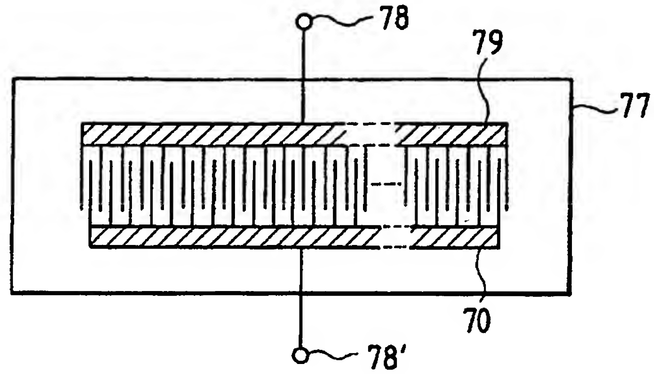



FIG. 7B

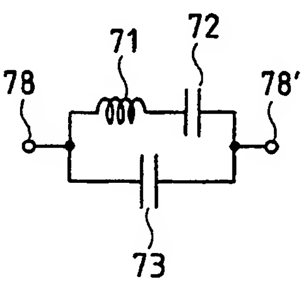



FIG. 7C

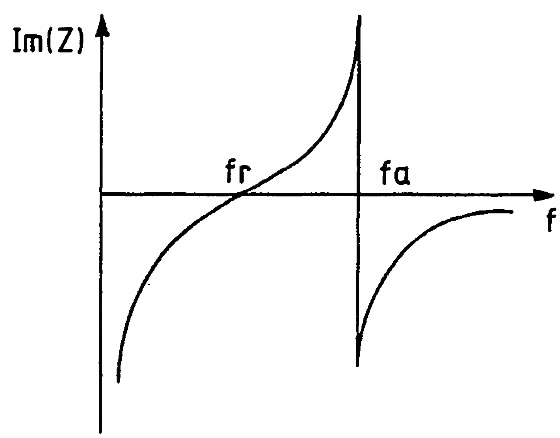


FIG. 8

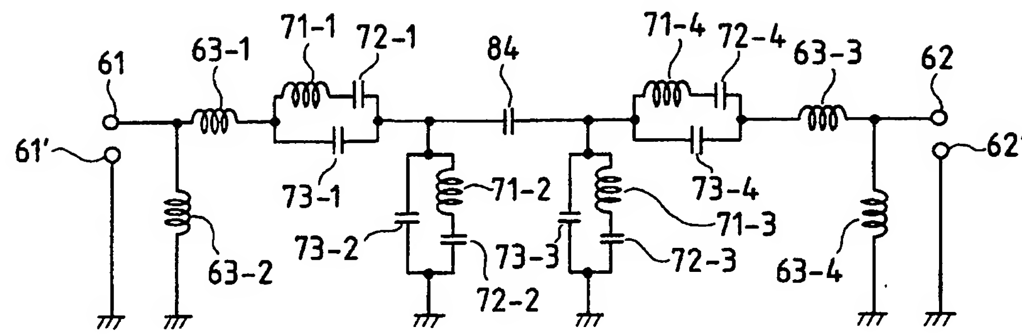

61
61'
63-1
63-2
71-1
72-1
73-1
73-2
71-2
72-2
84
73-3
71-3
72-3
71-4
72-4
73-4
63-3
63-4
62
62'

FIG. 9

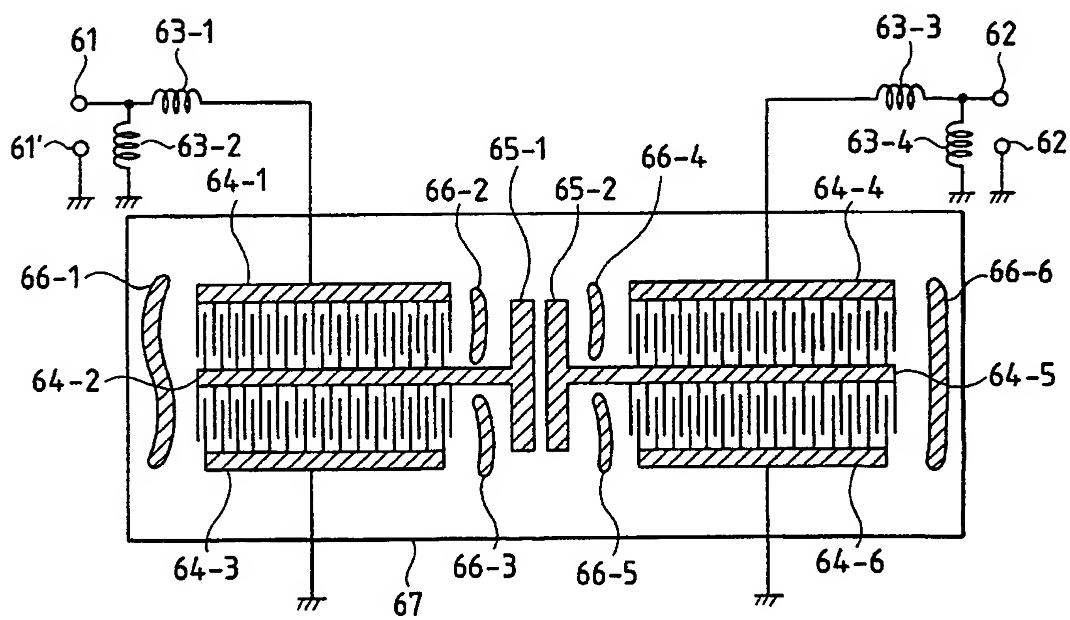

61
63-1
61'
63-2
64-1
66-1
64-2
64-3
66-2
65-1
65-2
66-4
66-3
66-5
67
63-3
62
63-4
62'
64-4
66-6
64-5
64-6

FIG. 10A

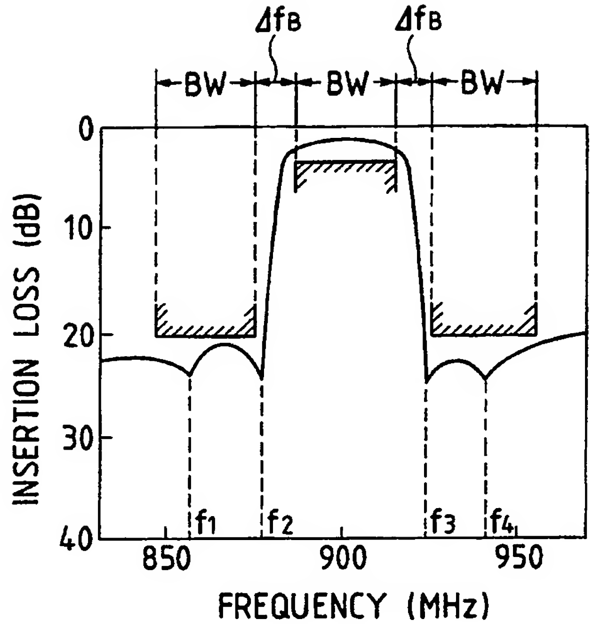



FIG. 10B

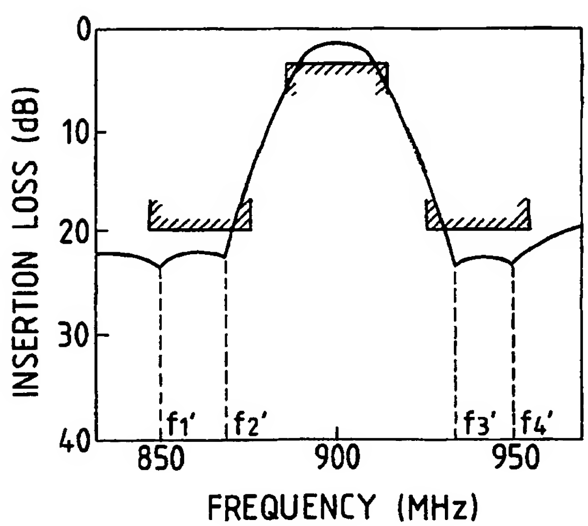


FIG. 12A

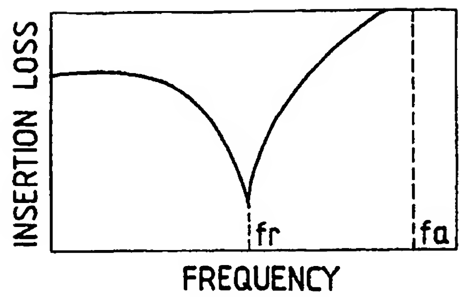



FIG. 12B

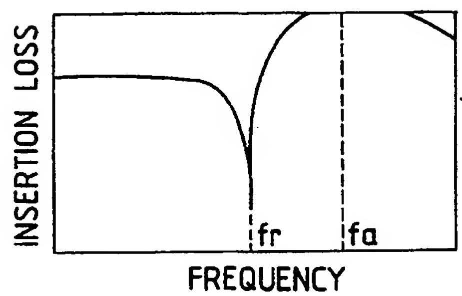



FIG. 13A

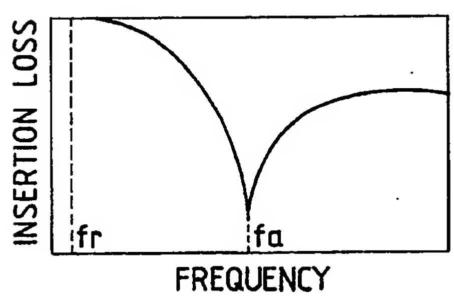



FIG. 13B

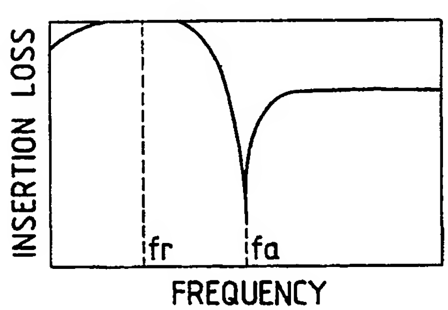
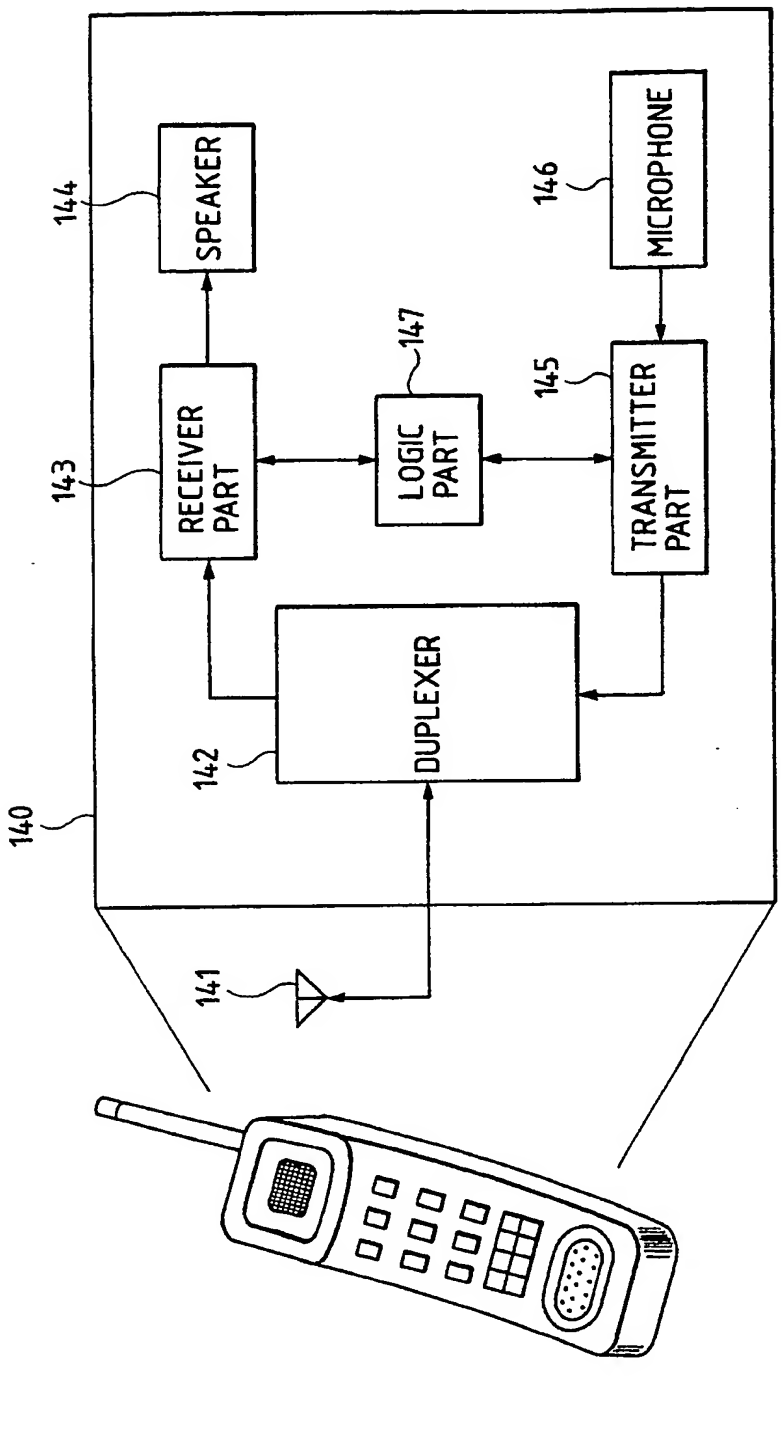


FIG. 14


140
141
142
DUPLEXER
143
RECEIVER PART
144
SPEAKER
147
LOGIC PART
145
TRANSMITTER PART
146
MICROPHONE